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Review Article

# Complications encountered in coronary chronic total occlusion intervention: Prevention and bailout

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ABSTRACT

Despite the continuing developments of improved medical devices and increasing operator expertize, coronary chronic total occlusion (CTO) remains as one of the most challenging lesion subsets in interventional cardiology. Percutaneous coronary intervention (PCI) of CTO is a complex procedure carrying the risk of complications that are responsible for significant morbidity and mortality. The complications can be classified as coronary (such as coronary occlusion, perforation, device embolization, or entrapment); cardiac non-coronary (such as periprocedural myocardial infarction); extra cardiac (such as vascular access complications, systemic embolization, contrast-induced nephropathy, and radiation-induced injury). Further, certain complications (such as donor vessel dissection or thrombosis) are unique to CTO–PCI. There are also complications related to specialized techniques, such as dissection/reentry and retrograde crossing techniques. A thorough understanding of the potential complications is critical to mitigate risk during these complex procedures.



## 1. Introduction

Chronic total occlusion (CTO) remains one of the most difficult subsets for the interventionists because of the perceived procedural complexity. Over the past few years, tremendous improvement in percutaneous coronary intervention (PCI) materials and equipments, as well as growth of new strategies have enabled us to treat with success even complex CTO. As PCI of CTOs are among the most complex procedures, it is critical to understand the potential complications with these procedures, and steps that could be taken for mitigating risk. Even in high volume and experienced centers, death may occur in up to 1% of patients, and in-hospital myocardial infarction (MI) may occur in up to 5% of cases, despite the conviction that PCI of CTO is a low-risk procedure.[1] There has been a progressive decrease in periprocedural MI and rate of death reflecting the evolution of PCI techniques, the development of dedicated equipments, and the utilization of adjunctive pharmacological therapy.[2] A systematic review by Patel and colleagues[3] of 65 studies with 18,061 patients and 18,941 target CTO vessels also revealed low risk for death (0.2%), emergent coronary bypass graft (0.1%), stroke (0.01%), MI (2.5%), and contrast nephropathy (3.8%). An analysis of 3482 patients and 3493 target CTO lesions from a total of 26 studies[4] revealed the complications consistent with above-mentioned

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**Table 1 – Complications of CTO–PCI.**

| | |
|---|---|
| Death | 0.7% |
| Urgent CABG | 0.7% |
| Cardiac tamponade | 1.4% |
| Collateral perforation | 6.9% |
| Coronary perforation | 4.3% |
| Donor vessel dissection | 2% |
| Stroke | 0.5% |
| MI | 3.1% |
| Q wave MI | 0.6% |
| Vascular access complications | 2% |
| Contrast nephropathy | 1.8% |
| Wire fracture and equipment entrapment | 1.2% |

**Table 2 – Proposed classification of coronary perforation.**

| Type | Definition |
|---|---|
| I | Focal extraluminal crater without extravasation |
| II | Pericardial or myocardial blush without an exit hole larger than 1 mm |
| III | Frank streaming of contrast through an exit hole larger than 1 mm |
| IV | Contrast spilling directly into anatomic cavity chamber such as coronary sinus and the right ventricle |
| V | Distal perforation related to the use of hydrophilic and/or stiff wires |

study (Table 1). For didactic purpose, CTO-related complications could be classified according to timing (acute and long term) and according to location (cardiac coronary, cardiac non-coronary, and extracardiac).

## 2. Acute coronary complications

### 2.1. *Perforations*

Coronary perforation occurs when dissection or intimal tear propagates outward to completely penetrate the arterial wall. It is one of the most dreaded complications of CTO–PCI which can lead to cardiac tamponade necessitating emergency pericardiocentesis and rarely, cardiac surgery to be controlled. Although perforations are common in CTO–PCI (27.6%) in one series,[5] most of them do not lead to serious consequences, and the risk of tamponade is low (approximately 0.5%). The risk factors predictive of perforation include the use of oversized compliant balloons (balloon-to-artery ratio >1.2) coupled with relatively high inflation pressure and hydrophilic and stiffer wires, particularly in calcified and tortuous arteries.[6–9] Use of debulking such as rotational atherectomy is an additional risk of perforation. Balloon advancement or dilatation on a subintimal wire results in major blood extravasation which may cause pericardial effusion possibly leading to cardiac tamponade, intramural hematoma or iatrogenic fistula between the coronary and cardiac cavity.[10] Balloons and equipments are advanced in subintimal space in antegrade or retrograde dissection and reentry in CTO–PCI. To avoid complications, operators need to make sure that equipments are within the adventitia, not in side branches and to size balloons appropriately using intravascular ultrasound (IVUS). Ellis-graded perforations fall into severity, ranging from small endovascular leaks into the adventia (type I) to frank extravasation into the pericardial space (type III).[6] Type IV include perforations into an anatomic cavity, such as the coronary sinus and right ventricle. Muller and colleagues, introduced type V perforation: distal perforation related to use of hydrophilic and/or stiff wires.[11] A proposed classification of perforation is shown in Table 2.[1,11] Type I perforations rarely lead to tamponade compared to type III perforations that are associated with a high rate of hemodynamic compromise (due to tamponade).

#### 2.1.1. *Prevention and treatment*

Prevention and minimization of the risk of bleeding is critical which can be accomplished in using unfractionated heparin for anticoagulation in contrast to bivalirudin and not using glycoprotein IIb/IIIa inhibitors during the procedure. With high activated clotting time (ACT), better anticoagulation can be achieved with heparin than bivalirudin. In addition, bivalirudin does not work in stagnant columns of blood which occurs in large bore guiding catheters leading to catheter thrombosis. Perforation has become important particularly with introduction of stiff wires for penetrating the proximal or distal cap of CTO. Dilatation of subintimal channel may result in vessel occlusion or perforation. It is also important to pay careful attention to tip hydrophilic wire (due to its propensity for subintimal passage and perforation of end capillaries) during attempts to deliver equipment; exchange a stiff or hydrophilic wire for a workhorse wire immediately after confirmation of successful crossing. The possibility of wire dissection can be avoided by meticulous angiography including dual injections and observing the wire path in orthogonal projections. Stiff guidewires induced perforation are of two types: perforation in the false lumen during wire advancement into false lumen; and distal small branch perforation after crossing the CTO lesions. Careful observation via angiogram is the most important consideration in diatal small branch perforations. These perforations very often cause delayed tamponade because operators are not able to detect them. It is advisable to use low balloon-artery ratio, high-pressure initial balloon inflation and over-sizing in heavy calcification. After initial balloon inflation, the deflated balloon should be kept in place; ECG should be watched for its reversal to baseline. The patient should be asked if there is relief of chest pain after balloon deflation. With a small contrast injection, if there is good distal flow without obvious extravasation of contrast, then the balloon should be pulled back in the guidewire to be reinflated should perforation occurs.[12]

In type I perforations, treatment is limited to careful observation for 15–30 min with repeated injections of contrast media. No further action is required if degree of extravasation does not increase or diminishes. However, increased extravasation is treated with reversal of anticoagulation and/or prolonged balloon inflation at or proximal to the perforated segment. Treatment of type II and III perforation should start with inflation of balloon over the site of perforation to occlude the flow (prolonged inflation of 10–30 min usually at 2 atm).[12] However, this attempt is sometimes difficult to continue because of ischemia (uncommon in CTO–PCI due to presence of collaterals). To relieve chest pain and avoid ischemia to distal area during balloon inflation, a microcatheter over another guidewire is positioned distal to site of perforation and the patient's own arterial blood via microcatheter is injected (microcatheter distal perfusion technique).[13] In case of life-threatening bleeds, reversal of heparin with protamine is indicated only after removal of all equipments from coronary artery. Infusion of fresh frozen plasma is the only means of reversing anticoagulation with bivalirudin. Some patients would require intravenous fluids, vasopressors, and urgent pericardiocentesis. Initial standard balloon catheter inflation is performed at site of perforation for at least 5–10 min for preparation of a perfusion balloon catheter and performing pericardiocentesis. Subsequent serial prolonged balloon inflation (for 20–30 min) may successfully seal the perforation or can provide time to prepare a polytetrafluoroehylene (PTFE) covered stent (Fig. 1). 7-F guiding catheter is ideal as the PTFE covered stent is bulky, rigid, and difficult to deliver. It may be difficult to negotiate through previously deployed stents, necessitating techniques such as distal anchor and use of delivery catheters, such as Guideliner catheter (Vascular Solutions, Minneapolis, MN).[14] It frequently requires dual guide technique to minimize bleeding in to the pericardium while preparing for cover stent delivery and deployment.[15] This technique involves contralateral access and use of a separate guide catheter to deliver stent. A second guidewire is advanced just proximal to the occluding balloon, which is then deflated and retracted, allowing passage of new guidewire and covered stent for complete closure of the perforation.[12,15] These PTFE-covered stent demonstrated quite high stent thrombosis rate (5.7%) and angiographic retstenosis (32%) in various clinical settings.[16] Even mild tortuosity may hamper the positioning this stent because of rigidity due to double-stent structure. The MGgurad stent (InspireMD, Tel Aviv, Israel) is a bare metal stent (BMS) covered by ultrathin polymer (polyehylene terephthalate) mesh sleeve on its external surface. The wrapping net of this stent is designed to diffuse stent pressure on the vessel wall, so in the site of perforation the net compresses homogeneously on the ruptured layers.[17] Yet this stent is not designed to fully cover the vessel wall. The pericardial covered stent (PCS, ITGI Medical, Or Akiva, Israel) highly deliverable balloon expandable fully covered stent allowing prompt deployment in case of emergency.[18] The PK Papyrus (Biiotronik, Berlin, Germany) is a sixth generation BMS of cobalt-chromium alloy, thinner struts of which allow exceptional flexibility and deliverability, even in challenging vessels (Fig. 2). The polyurethane covering the stent is only 90 μm thin resulting in 24% reduction in diameter over a sandwich design. It is 5-F and 6-F compatible, thereby eliminating the need to switch access catheters during the emergency situations. Type II and III perforations unresponsive to the above measures would require emergent cardiac surgery. Type IV perforation usually does not require treatment. Type V perforations resulting from distal guidewire manipulation should first be treated by proximal balloon inflation. Alternatively, and particularly in case of persistent leakage, embolization may be considered with microcoils, gelfoam, clotted autologous blood, thrombin, polyvinyl alcohol, and subcutaneous tissue.[12,17,19] When injecting material in a perforated artery, care must be taken to prevent spilling the material in other coronary arteries or branches by inflating a balloon proximal to the injection site, or injecting through the distal lumen of an inflated over-the wire-balloon.

### 2.2. *Aortocoronary dissection*

Aortic dissection may complicate any PCI, but is common with CTO–PCI and most frequently occurs in right coronary artery. It could be the result of guiding catheter trauma (large-caliber guide catheter with aggressive shapes, such as Amplatz), forceful contrast injection through a wedged catheter, or by balloon rupture.[12,14] Dissection may be limited to the coronary sinus of valsalva, may extend to the proximal ascending aorta, or extend beyond the ascending aorta (Table 3).[20] Use of guide catheters with side holes and/or avoiding contrast injection during damped pressure may prevent this complication. Once the dissection occurs, it is important to stop further coronary injections and stent the ostium of the coronary artery. Extension of the dissection into proximal ascending aorta of

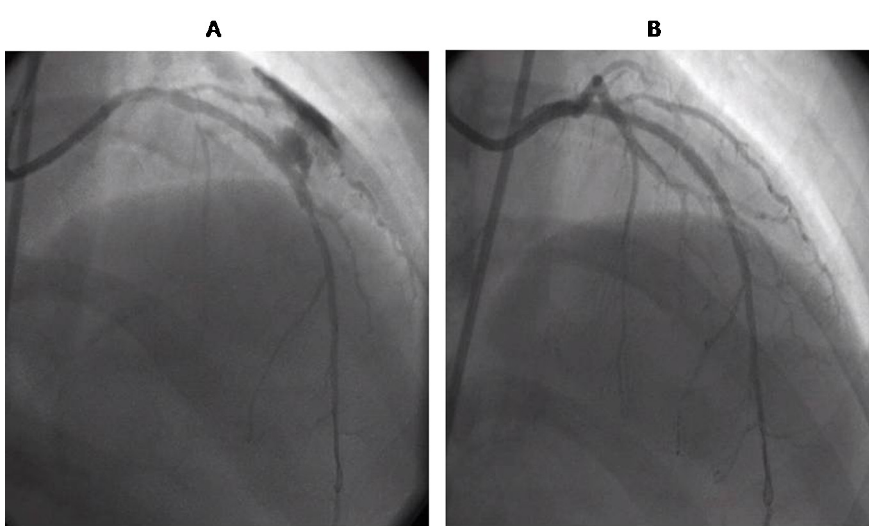


**Fig. 1 – Bailout of Ellis type III perforation during left anterior descending (LAD) coronary artery chronic total occlusion (CTO) intervention. (A) Type III perforation in 50-year-old gentleman after deployment of drug-eluting stent (DES) in mid LAD. (B) Final result after Graftmaster (Abbott Vascular, USA) covered stent has been deployed.**

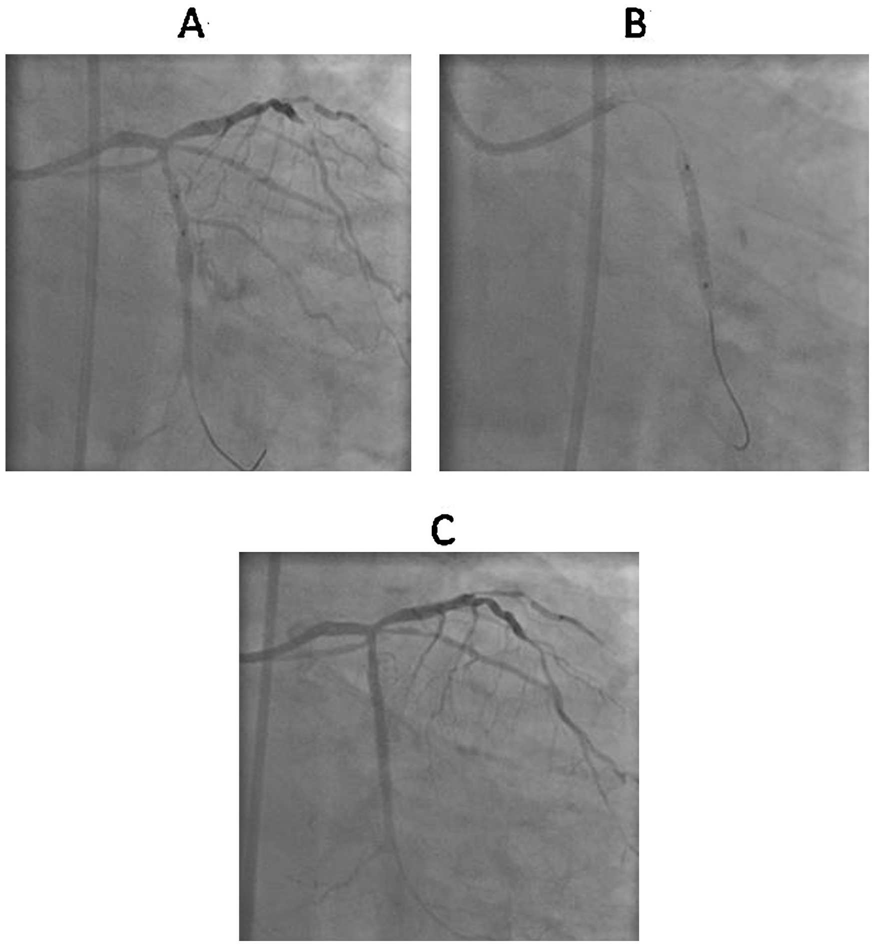


**Fig. 2 – Bailout of Ellis type III perforation in left circumflex (LCx) artery CTO intervention. (A) Type III perforation in distal LCx after in-stent balloon dilatation. (B) Deployment of PK Papyrus (Biotronik, Berlin, Germany) covered stent after advancement of Graftmaster stent has failed. (C) Final result.**

less than 40 mm can be managed by watchful expectancy or stenting of the coronary ostium with conventional stent or covered stent (Fig. 3). Dissection extending beyond 40 mm into aortic root, development of aortic regurgitation, and involvement of supra-aortic vessels would require emergent surgery.[12,20]

### 2.3. *Distal vessel dissection*

Distal dissection occurs when wire crossing in subintimal position causes hematoma that compresses the true lumen. If reentry fails, it may be best to wait for 2–3 months before reattempting PCI, to allow time for healing of the dissection. IVUS may be performed and stenting is considered in case of tissue flap or flow limitation.[12]

**Table 3 – Classification of iatrogenic aortic dissection.**

| Class | Description |
|---|---|
| 1 | Limited to ipsilateral coronary sinus of sinus of Valsalva |
| 2 | Extending to the proximal ascending aorta (<40 mm) |
| 3 | Extending beyond the proximal ascending aorta (>40 mm) |

### 2.4. *Air embolism*

Introduction of air into the coronary artery is potentially dangerous, resulting in 'air lock', causing abrupt occlusion of the vessel, possible cardiac arrest and/or MI. It occurs due to incomplete aspiration of catheters, entry of air into manifold system during the change of contrast, balloon rupture, and insinuation of air with balloon catheter introduction.[21] Air embolism is more common in CTO–PCI than non-CTO–PCI because of frequent exchange of devices, prolonged duration of procedure, engagement of catheters in occluded segments, or dissection planes and "trap balloon" technique. Its occurrence could be prevented by careful aspiration of catheters, especially in the setting of trap balloon that sucks air and meticulous flushing of coronary equipment. Once air lock develops, therapy may include ventilation with 100% oxygen intravenous fluids, atropine ionotropic agents, intaaortic balloon counterpulsation,

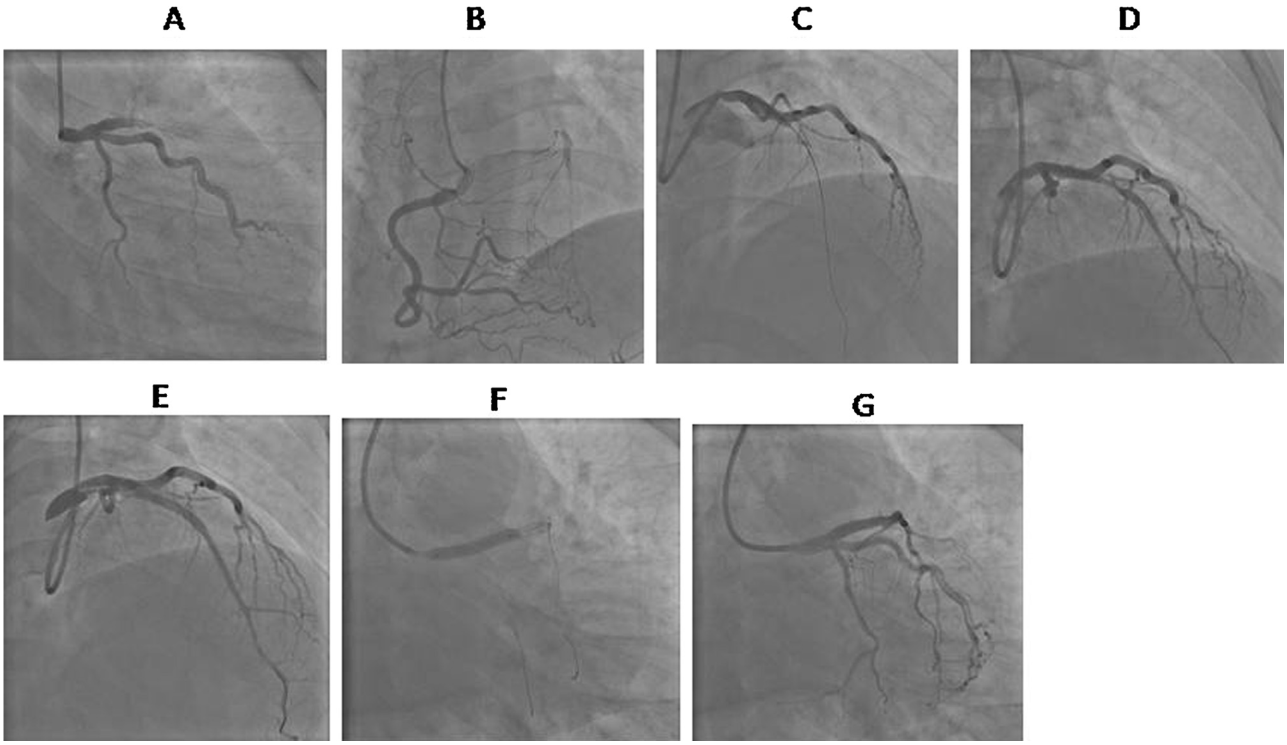


**Fig. 3 – Aortocoronary dissection after stenting of mid LAD with DES. (A) Coronary angiography depicting chronic total occlusion (CTO) of mid LAD. (B) Good collateral from right coronary artery to LAD. (C) The CTO crossed with coronary guidewire. (D) Predilatation of the lesion with 2.5 mm × 12 mm balloon. (E) Dissection of left main coronary artery (LMCA) with retrograde extension into aorta following deployment of 3.0 mm × 24 mm DES in mid LAD. (F) LMCA stenting with 4 mm × 23 mm DES sealing the entry point of dissection. (G). Final result after high-pressure in-stent dilatation with non-compliant balloon.**

forceful injection of contrast and saline for dissipation of the air bubbles, guidewire disruption of distal air bubbles, extraction of bubbles with thrombectomy catheters, or over-the wire balloon (Table 4).[21]

### 2.5. *Device embolization or entrapment*

A tortuous and calcified coronary anatomy increases rigidity posing challenges in device delivery in CTO vessels. Stent loss[22] or wire entrapment[23] may ensue the risk of which may be increase during retrograde wiring and stent delivery. Adequate vessel preparation is critical prior to attempting to deliver stents. Wire entrapment may be avoided by never rotating the wire >180° in one direction, and may sometimes be relieved by superselective injections of nitrogycerine or verapamil via mirocatheter. Knuckle wire should be pushed, but never rotated for fear of wire knotting. It is important that tip of antegrade and retrogarde microcatheters over the same wire should not kiss to avoid entrapment. Overtorquing of microcatheters should also be avoided. The embolized stent could be retrieved using various snares.[24] Often crushing or deployment of lost stent with balloon or stent is more efficient than retrieval (Table 5).[21] Wire braiding technique (removal of stent with two twisted wire) and inflation of small balloon distal to the stent with subsequent removal of whole system may also be employed.[21]

**Table 4 – Treatment of air embolism.**

- Ventilation with 100% oxygen
- Intravenous fluids, atropine or vasopressors for hemodynamic support
- Intraaortic balloon counterpulsation
- Wire or balloon catheter to induce 'air lock' dissipation
- Catheter aspiration of air embolus
- Forceful injection of saline or contrast
- Treatment of no-reflow phenomenon with standard vasodilators (adenosine, verapamil, nitroprusside)
- Emergency CABG

**Table 5 – Management of stent embolization.**

- No treatment for peripherally embolized small stents
- Deployment of the stent with balloon or second stent if on wire
- Crushing of the stent if off wire
- Retrieval with a snare
- Removal with twisted wires
- Inflation of a small balloon distal to the stent and removal of the whole system

### 2.6. Complications of antegrade dissection and reentry

Antegrade dissection and reentry is an essential component of CTO–PCI. The subintimal tracking and reentry (STAR) and contrast-guided STAR are subject to relatively high rates of perforation and restenosis (Table 6), because of need for stenting long segment of the artery.[25] These techniques may also carry higher risk of periprocedural MI and restenosis because of occlusion of side branches. Use of these techniques is suboptimal in the left anterior descending artery where numerous side branches (septals and diagonals) could be sheared off and not recovered.[26] In one study, a successful STAR technique was associated with a 57% of reocclusion rate.[27] Reentry leads to loss of distal visualization of the segment by compressive hematoma. This can be prevented by avoiding creation of a large subintimal space (with antegrade injection), aggressive wire manipulation, or extended knuckling.

Recent technologies, ''CrossBoss'' catheter, Stingray balloon, and Stingray reentry guidewire (Boston Scientific, Natik, MA) have addressed the limitations of wire-based reentry methods and have provided a reproducible method for successfully gaining reentry into the true lumen of artery. With STAR, the operator tries to gain subintimal wire position as soon as possible, and extends a dissection to the distal artery where all significant-sized individual side branches are sequentially attempted to be reconnected to the true lumen. With ''CrossBoss'' catheter and Stingray reentry devices, over one-third of cases can be traversed via the true lumen with the crossing catheter without dissection. In case of subintimal position, this catheter is advanced only to the angiographic true lumen reentry point where the reentry device is employed to regain the true lumen without extending the dissection any further than necessary. Reentry is attempted in a major epicardial vessel rather than into individual branch vessels. The author considers STAR a method of last resort to open a CTO and this dedicated system as a frontline device after conventional wire failure. If a hematoma forms due to subintimal wire entry, aspiration through a microcatheter may decompress the hematoma and allow reexpansion of the distal true lumen (Subintimal TRAnscatheter Withdrawal [STRAW] technique).[26]

**Table 6 – Comparative complications of chronic total occlusion vs non-chronic total occlusion interventions.**

| Complications | CTO–PCI (antegrade approach) | CTO–PCI (retrograde approach) | Non-CTO–PCI |
|---|---|---|---|
| Main vessel perforation | ++ | ++ | + |
| Distal wire perforation | ++ | + | + |
| Collateral perforation | – | ++ | – |
| Aortic dissection | ++ | ++ | ± |
| Side branch occlusion | ++ | + | ± |
| Air embolism | ++ | + | ± |
| Donor artery thrombosis | + | ++ | – |
| Stent loss | + | ++ | ± |
| Wire entrapment | + | ++ | ± |
| Cardiac biomarker elevation | ++ | ++ | + |
| Systemic embolism | + | ++ | ± |
| Radiation injury | ++ | ++ | + |
| In-stent restenosis | ++ | ++ | + |
| Stent thrombosis | ++ | ++ | + |
| Coronary aneurysm | + | ++ | – |
| Contrast nephropathy | + | ++ | ± |

The complications of various techniques have been graded such as 'absent' (–), 'may be' (±), uncommon' (+), and common (++), according to the rationale explained in the text. CTO, chronic total occlusion; PCI, percutaneous coronary interventions.

## 3. Complications pertaining to the retrograde approach

### 3.1. Donor artery injury

There is an augmented risk of donor artery injury owing to spasm, dissection, or thrombus formation. This complication is observed during antegrade approach of recanalization of CTO as well, when donor artery angiography is performed to visualize the distal segment distal to the occlusion via collaterals, but risk is higher with the retrograde approach. Equipment withdrawal or externalization of snared wire may cause the guide catheter to deeply engage the vessel leading to dissection. Given the typical longer duration of CTO procedures, and having microcatheters in the vessel, CTO–PCIs are more susceptible to donor artery thrombosis (Table 6). Back bleeding and good flushing should be allowed after removal of any equipment. ACT should be monitored at least every 30 min to maintain it in between 300 and 350 s. Stenting of donor artery should be done in case of dissection. Aspiration thrombectomy and additional IIb/IIIa inhibitors might be required with donor vessel thrombosis.[10]

### 3.2. Collateral channel injury

Complications exclusive to the retrograde approach are guidewire and balloon kinking or entrapment into collateral channel (CC), dissection, perforation, and hematoma formation (Table 6). Many CC ruptures are benign and do not require further treatment apart from abandoning that CC and trying for another. The channel dilator ([Corsair] Ashahi Intec, Japan) is safer than a balloon and rarely causes CC dissection or perforation even with excessive tortuosity. While advancing the channel dilator, if septal wire shows excessive kinking, the wire needs to be withdrawn to prevent septal perforation. Septal perforations usually do not lead to adverse consequences, although septal hematomas[28] and even tamponade[29] have been reported. In one case report, septal hematoma manifesting as an echo-free space caused asymptomatic bigemini and severe chest pain, and resolved spontaneously.[30] Perforation into cardiac chamber usually does not result in complications; however, balloon dilatation or advancement of additional device should be avoided.

Epicardial CC perforation can rapidly lead to tamponade and may be difficult to control. These CC should never be dilated to minimize the risk of perforation. Epicardial collateral wiring is safer in patients with prior CABG or other surgery requiring pericardial entry, as bleeding may be contained within pericardial space.

These CC perforations are prevented by meticulous wire manipulation through CC, ensuring position of wire prior to advancement of channel dilator, cautious injection of contrast through its tip ensuring that back bleeding is possible prior to injection of contrast, withdrawing epicardial collateral wire after ascertaining no perforation at the end of procedure, avoiding surfing the epicardial CC. Negative pressure from the wedging microcatheter or channel dilator might sometimes be sufficient to seal the ruptures. Advancing microcatheter and coiling from both sides that feed the collateral might to be required to address perforations.[14] It is advisable to perform dual contrast injection from both sides to confirm that there is no bleeding from the antegrade or retrograde side.

### 3.3. *Wire externalization-related problems*

In retrograde true lumen puncture or reverse controlled antegrade or retrograde subintimal tracking technique (CART), the crossing wire is exchanged for externalization wire after a microcatheter or channel dilator is delivered into antegrade guide catheter. The wire used for externalization needs to be as long as possible. Extending short guidewires is unadvisable for this purpose because of the possibility of kinking or separation. The wire should be lubricious and kink-resistant but not so supportive as to damage tortuous and fragile CC. In general, a 330 cm RG 3 (Ashahi Intec, Japan) guidewire is preferable. Avoidance of deep throating of retrograde guide catheter to prevent ostial damage is of utmost importance during externalization. CC needs to be protected with a microcatheter or channel dilator. Flushing after reverse CART can result in hydraulic dissection. Ballooning and stenting is performed after 20–30 cm wire is externalized. Distal landing zone for stents is identified by retrograde contrast injection. The stiff part of the wire should be under cover of channel dilator or microcatheter. The end of the externalized wire should never be pulled unless the CC is protected.[31] To remove the externalized wire, the channel dilator should be renegotiated into the antegrade guide catheter. It must protect the CC until the soft wire tip is back. In order to avoid ostial dissection because of externalized wire retraction, both antegrade and retrograde guide catheters are disengaged from the coronary ostium and pulled back 3–4 cm into aorta. This follows removal of externalized wire synchronized with heart beat taking care not to kink it. Then channel dilator is removed with clockwise rotation.[31]

Sometimes retrograde advancement of wire into antegrade guide catheter fails in event of aorto-ostial lesions, extremely tortuous artery, or whenever there is poor retrograde wire control. This difficulty in antegrade wiring is overcome by snaring. It is best to snare the tip or soft part of the wire. Snaring on the stiffer part of externalization wires leads to kinking that can shear the antegrade guide tip. The wire is gently swept into the antegrade guide and taken care not to unravel the coils. Snaring of polymer jacketed wire strips off the polymer. Therefore, back bleeding is of paramount importance after externalization.

## 4. Acute noncoronary cardiac complications

Post-procedural MI is an infrequent complication of CTO–PCI caused by various mechanisms such as side branch occlusion at or proximal to the CTO; CC occlusion or injury; injury of the target vessel distal to CTO segment caused by subintimal wire passage and/or stenting; donor vessel injury and/or thrombus and air embolism as discussed earlier.[14]

## 5. Acute extra-cardiac complications

### 5.1. *Vascular access injury*

The probability of vascular access complications is increased with CTO–PCI as compared to regular PCI, given larger sheaths and dual access. The risk of such complications could be minimized by a combination of radial and femoral access, bi-radial approaches,[32] micropunture technique, utilizing fluoroscopic landmarks, or ultrasound[33] prior to obtaining femoral access. Retrograde CTO–PCI may be associated with higher rate of post-procedure enzyme leak, but it is unclear if it impacts on clinical outcome.

### 5.2. *Contrast-induced nephropathy (CIN)*

CTO–PCI entails a significant risk as the long procedure requires large contrast volume, and often a second or third attempt is required for successful recanalization.[34] Patients with high risk of CIN should be identified wherein utilization of contrast needs to be monitored closely. The first line of prevention consists of strict limitation of contrast amount and avoidance of repeated use of contrast within a short period of time.[35] Other prophylactic modalities could be adequate hydration, iso-osmolar contrast, and/or sodium bicarbonate.

### 5.3. *Radiation injury*

CTO–PCI, typically due to longer time involved, is one of the predictors of radiation dose. Radiated-related injury, acute (mainly skin injury) or delayed (increased risk for cancer and cataract), has been recognized in both the patient and the operator.[36] Radiation skin injury could be a deterministic, dose-dependent complication of CTO procedure.[37,38] It is critical to follow air kerma, and not just the fluoroscopy time as has been traditionally done. Risk of skin injury is significant if more than 5-Gy air kerma doses is administered. It is certainly worthwhile considering stopping the procedure if CTO is not crossed by 7 Gy. It is important to have a standardized radiation safety program in place while embarking on CTO program. Several measures can be taken to minimize radiation exposure during CTO–PCI.[14,39]

1) Limit fluoroscopy use
2) Limit use of cine-angiography
3) Utilizing low magnification
4) Utilizing collimation
5) Use of lowest frame rate
6) Frequent rotation of image intensifier
7) Paying attention to the position of the table and image intensifier.
8) Avoidance of steep angles
9) Injecting CTO collateral donor vessel before starting cine-angiography

**Table 7 – Frequency of complications of chronic total occlusion interventions.**

| Author | Year | Patient (n) | Success (%) | Retrograde (%) | Death (%) | MI (%) | CABG (%) | Tamponade (%) |
|---|---|---|---|---|---|---|---|---|
| Suero et al.[45] (MAHI) | 2001 | 2007 | 69.9 | 0 | 1.3 | 2.4 | 0.7 | 0.5 |
| Prasad et al.[2] (Mayo Clinic) | 2007 | 482 | 70 | 0 | 0.4 | 8 | 1.7 | 0.8 |
| Kimura et al.[46] | 2009 | 224 | 90.6 | 62.6 | NR | 4.5 | 0.4 | NR |
| Rathore et al.[5] | 2009 | 83 | 86.2 | 100 | 0 | 4.5 | 0 | 1.1 |
| Tsuchikane et al.[47] | 2010 | 93 | 96.8 | 100 | 0 | 5.4 | 0 | NR |
| Morino et al.[48] (J-CTO) | 2010 | 498 | 87.7 | 25.7 | 0 | 2.3 | 0 | 0.4 |
| Galassi et al.[49] (ERCTO) | 2011 | 234 | 64.5 | 100 | 0.4 | 2.1 | 0 | 0.8 |

*Abbreviations*: CABG, coronary artery bypass graft; CTO, chronic total occlusion; ERCTO, European CTO club; J-CTO, Japan CTO Club; MAHI, Mid America Heart Institute; NR, not reported.

10) Use of radiation monitor providing real time feedback on operator radiation exposure
11) Use of additional shielding, such as X-drape (AADCO Medical, Randolph, VT)
12) Paying continuous attention to the air kerma radiation dose and using it for modifying procedural plan.
13) Separating procedural attempts by adequate time intervals.

## 6. Long-term complication

Patients undergoing PCI of CTO can have the same late complication (in-stent restenosis and stent thrombosis) that patients with non-CTO–PCI might have. Coronary aneurysms[40] have been reported as a late complication which is more common in retrograde interventions as compared to antegrade.[41]

## 7. Complication rates from published studies

Saito[42] reported the dissection or minor perforation of the target artery or CC in 13% of cases. Sianos et al.[43] described septal rupture and hematoma, MI, transient ischemic attack, and wire entrapment in 6.9%, 4%, 0.6%, and 0.6% respectively. Wu et al.[44] described the occurrence of cardiac tamponade and donor vessel dissection in 3.5% and collateral perforation in 3.5% cases. No patient in their series experienced death and emergent CABG. Several other series have also reported acceptable complications of CTO–PCI (Table 7).

## 8. Conclusion

CTO is the last frontier in the field of interventional cardiology. Despite the development of new devices and techniques, certain complications still persist. Improved success rate in CTO–PCI should be in conjunction with the least possible risk of complications. Avoidance of the complications is best accomplished by operator expertise and preventive approaches. Having the thorough understanding of potential complications is the first step in mitigating the risks. Treatment should be instituted rapidly and aggressively once complications are recognized to achieve the best outcome. No matter how experienced the operator is, complications can never be completely avoided, rather they would teach humility and be a continuous source of education.

## Conflicts of interest

The author has none to declare.

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